This paper has been cleared by ASC 99-2379

Panoramic Night Vision Goggle Update

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ABSTRACT

Operational test and evaluation of a first-ever 100 degree field of view (FOV) night vision goggle is currently underway at several locations. Testing is being conducted onboard F-15C, F-15E, and more recently F-117,C-5,C-130, CH-47D, and AH-1 aircraft as well as with special operations ground personnel. In the near future, testing will include other ejection seat, transport, and rotorcraft platforms. Two configurations of the Panoramic Night Vision Goggle (PNVG) are being evaluated. The first version design (PNVG I) is very low in profile to fit underneath a visor and can be retained by the pilot in the case of an ejection. The second version (PNVG II) resembles the currently fielded 40 degree FOV AN/AVS-6 and F-4949 NVGs and is designed for non-ejection seat aircraft and ground applications. During flight evaluations, subjective questionnaires are being used to collect pilot ratings in order to compare capability of the 100 degree FOV PNVG to that of the 40 degree F-4949 across different operational tasks. The SA-SWORD technique is being used in order to produce situational awareness ratings for statistical analysis. The paper will discuss current findings and pilot feedback of the PNVG I system on F-15C and F-15E aircraft only.

INTRODUCTION

A Small Business Innovative Research program phase II program that ended in July 1999 resulted in the delivery of seven PNVG I and five PNVG II prototype systems. The PNVG I version (Figures 1 and 2) was initially designed for ejection seat aircraft. A better center of gravity compared to the currently fielded F-4949 should be less fatiguing during longer flights. The low profile design will potentially allow for ejection by permitting retention of the system on the head throughout the ejection sequence. Retention of PNVG I may also aid evasion and rescue. The PNVG II approach, which looks more like a traditional goggle, should be more robust and will attach to any existing AN/AVS-6 or F-4949 mounting system. This version is intended for transports, helicopters, and ground personnel. Both PNVG I and II will provide a 100 degree horizontal by 40 degree vertical (100^o H X 40^o V) intensified field of view (FOV) (Figure 3.). This represents a 160% increase of the warfighter's intensified image (I^2) FOV compared to currently fielded 40^o F-4949 system (Figure 4.). Subjective questionnaires are being used to collect pilot ratings during recent flight evaluations to allow comparisons of the PNVG versus F-4949 across different operational tasks. This paper addresses pilot feedback from F-15C and F-15E aircraft during PNVG I use. In order to produce situational awareness (SA) ratings for statistical analysis, a technique referred to as SA-SWORD was recently introduced to the test activity (only limited feedback is available).

Figure 1. PNVG I in an F-15E (Front Cockpit).

Figure 2. PNVG I in an F-15E (Rear Cockpit).

BACKGROUND

NVGs with FOVs ranging from 30 degrees to 45 degrees have been used in military aviation for more than 20 years. The vast majority of NVGs (AN/AVS-6 and F-4949) provide a 40 degree binocular FOV. Because each ocular uses only a single I^2 tube, increased FOV for these NVGs can only be obtained at the expense of resolution.[1,2] The I^2 tube has a fixed number

Report Documentation Page						*Form Approved* *OMB No. 0704-0188*
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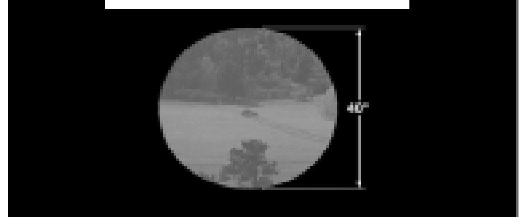
1. REPORT DATE **1998**		2. REPORT TYPE **N/A**				3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Panoramic Night Vision Goggle Update**						5a. CONTRACT NUMBER
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)						5d. PROJECT NUMBER
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory Human Effectiveness Directorate 2255 H Street Wright Patterson AFB, OH 45433-7022**						8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)						10. SPONSOR/MONITOR'S ACRONYM(S)
						11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**						
13. SUPPLEMENTARY NOTES **The original document contains color images.**						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**5**		

Figure 3. PNVG FOV.

of pixels (picture elements). If the pixels are spread over a larger FOV, the angular subtense per pixel increases proportionally thus reducing resolution. An extensive survey of U.S. Air Force NVG users showed that increased FOV was the most desired enhancement by aircrew members. Resolution was a close second.[3,4] This was a motivating factor for the development of an enhanced NVG capability. Although FOV was identified as the most desired performance parameter to improve upon, the exact benefits have not yet been adequately quantified. Previous studies suggest FOV produces performance advantages: A study using a critical tracking task showed best performance at 80 or 100 degrees. An increase from 40 to 80 degrees greatly reduced subjects' workload.[5] Another study included a series of low altitude maneuvers in Cobra and Lynx rotorcraft. The results indicated 100 degree to unrestricted FOV required only moderated pilot compensation. The results also showed pilots flying with restricted FOV reported better flying performance than they actually exhibited. Restricted FOV inhibited detection of multiple cues concurrently. Also, the small FOV required more head movement and a different scan technique while large head movements led to aircraft control difficulty and disorientation.[6] A third study had subjects visually acquire targets, remember the location of the target, and monitor target threat status while performing a secondary task. Error decreased as FOV increased until a FOV of 90 degrees was reached. Secondary task performance increased as FOV inceased.[7]

Figure 4. PNVG FOV.



METHOD

Several operational utility evaluation (OUE) efforts have been initiated to evaluate the PNVG. Laboratory experiments are also being performed to address specific questions regarding performance and SA effects attributable to the PNVG FOV. The objective of the OUE is to expose the PNVG to the operational environment to investigate the impact the technology has on mission effectiveness and survivability. The OUE process includes the development of new tactics which result from the application of new technology. The data presented here were produced via questionnaires completed by operational test pilots who flew with the PNVG during evaluation flights at the 422nd Test and Evaluation Squadron at Nellis AFB, Nevada. Data are included from 16 different sorties: 6 F-15E flights and 10 F-15C flights. At the date of this writing, a total of 12 pilots participated in the evaluation flights. Four of the 12 pilots each flew two different sorties. Three of the four duplication flights were in F-15C's. Both air-to-air and air-to-ground missions were completed. A post-flight questionnaire was developed to collect pilots' impression of the PNVG across different interest areas during each mission.

QUESTIONNAIRE AND RATING SCALE: A rating scale was developed to compare pilots' experience with PNVG versus their previous experience with F-4949s. It was not feasible to directly compare the PNVG to F-4949 on a flight by flight basis. Instead, the questionnaire instructions asked pilots to compare their recent experience with the PNVG vs. their past experience with F-4949s. All of the pilots had significant flight experience with the conventional F-4949 NVGs. A rating methodology was developed to allow the pilots to quantify their comparison of the NVGs. Table 1 shows the rating scale developed for the questionnaire. Questions were formed for the following categories: 1) Fit, Function, and Human Factors, 2) Cockpit/Cockpit Lighting Compatibility, 3) Image Quality, and 4) Tactical Employment. Where possible, comparison ratings were collected. Where appropriate, yes/no format questions were asked. Comments were solicited at the end of each category section of the questionnaire. A final section of the questionnaire was dedicated to additional comments designed to collect information about the advantages and disadvantages of the PNVG.

RATING SCALE		RESPONSE
1	Very Ineffective	PNVG performance is significantly less than that of the F-4949 and significantly affects safety of flight or detracts from successful task/mission accomplishment.
2	Ineffective	PNVG does not perform as well as the F-4949 and detracts from task/mission accomplishment.
3	Same	PNVG and F-4949 performance does not differ.
4	Effective	PNVG performs better than the F-4949 and enhances task/mission accomplishment.
5	Very Effective	PNVG performance is significantly better than the F-4949 and significantly enhances safety of flight or adds to successful task/mission accomplishment.

Table 1. PNVG questionnaire rating scale.

SA SPECIFIC COMPARISONS: The questionnaire was modified in order to focus responses on a comparison of the effect of the PNVG and F-4949 goggles on pilot SA during seven operational tasks including: 1) Threat detection, 2) Formation and tactics, 3) Mutual support, 4) Target acquisition, 5) Target identification, 6) Target attack, and 7) Survivability. A final question is used to capture a comparison of overall SA. The comparisons were made relative to the following pilot produced definition of SA: *Time and space analysis allowing you to have total awareness of where everyone in your flight is and how their actions are going to react with yours in various environments, threat conditions, weapons systems capabilities, and human factors.* The comparisons were derived using the SA-SWORD rating technique.[8,9] Table 2 shows an example comparison set for a single task. The data is analyzed using inferential statistics. At the time of this writing, feedback from only one flight has been collected via the new questionnaire.

Task: **Threat Detection**	If not equal, how much more or how much less? Barely							Substantially
Night without NVGs results in (___ more)(___ equal)(___ less) SA than F-4949								
Night without NVGs results in (___ more)(___ equal)(___ less) SA than PNVG								
PNVG results in (___ more)(___ equal)(___ less) SA than F-4949								

Table 2. SA-SWORD questionnaire format.

RESULTS

The following paragraphs present the questionnaire data collected to date. The information represents averages derived across all 16 sorties. It is indicated where feedback is specific to an aircraft type (F-15C or F-15E).

DESCRIPTIVE INFORMATION: Average takeoff time was 42 minutes after local sunset. Average duration of the flight was 1 hour 32 minutes (1:32). Illumination conditions were described as high for slightly more than half the flights (62.5%). Average moon presence was 68.3% and the observed weather was described as clear for the majority of the flights (91.6%).

FIT, FUNCTION, AND HUMAN FACTORS RATINGS: Pilots found the PNVG to be easier to don than the F-4949 (mean rating = 4.25). For weight and center of gravity, the operating comfort of the PNVG was rated as better than the F-4949 (mean rating = 3.94). In the stowed position, ratings indicated similar comfort compared to the F-4949 (mean rating = 3.67). Stability of the PNVG during head movements, G loading, and vibration was rated as slightly better than F-4949 (mean rating = 3.66). In some cases, the helmet was not custom fit to the pilot. Questions concerning PNVG position and focus adjustability indicate that this is an area of design criticism. Both position (mean rating = 2.67) and focus (mean rating = 2.87) were rated as the "same" to "ineffective" compared to F-4949. Peripheral vision around the PNVG and the ability to look under the PNVG to view cockpit instrumentation was rated as very similar to F-4949 (mean rating for both = 3.07). The compatibility of the PNVG with the use of a clear visor was rated as better than F-4949 compatibility (mean rating = 3.75).

FIT, FUNCTION, AND HUMAN FACTORS COMMENTS: This section includes selected comments that represent the most negative and most positive feedback collected. These comments are intended to reflect the amount of variability among all of the recorded comments. It should be kept in mind that criticism is typically the purpose of commenting during OUE. Regarding the effort to don the PNVG, no negative comments were recorded. The positive comment follows: *"No compression, very comfortable. Much better ergonomics."* For weight and CG in the operating position, the following negative comment was recorded: *"PNVG feels a little heavier than the 4949. My jaw was tired after the mission. Lots of pressure on the mask."* The associated positive comment: *"Helmet fit was poor. Snaps are close to PNVGs and make them difficult to use. Much more comfortable and less cumbersome than 4949 in operating position."* For weight and CG in the stowed position, only one comment was recorded: *"PNVGs in stowed position were uncomfortable and snapped down when pulled > 2.5-3 g's. When down, PNVG was very stable during maneuvering."* The negative comment for PNVG stability was: *"The helmet fit is key. If the helmet is sloppy, it's virtually impossible to get a good look at the true capability of the PNVGs."* The associated positive comment: *"At or above 5G's the "Trapeze" began to rest on my forehead slightly. Never uncomfortable and never lost the image."* The following comments cover PNVG position and focus adjustability. Negative: *"Adjustments too hard with gloves on, hit lateral stops on width adjustment, can't achieve 20/20 focus, focus knobs too course and too hard to actuate with gloves & visor on, lack of vertical adjustment in flight was bad."* The most positive comment: *"Small movements to focus is harder."* For focus adjustability, the negative comment: *"Ran out of focus travel.*

Could have made binocular focus crisper than it was with more adjustability. Also, would greatly increase usability if outside tubes were also adjustable." The positive comment: *"Focus is too sensitive, especially for in-flight."* For peripheral vision around the PNVG, only one comment was recorded: *"Peripheral vision outside PNVGs was reduced significantly. Requires slightly more effort to look in cockpit (have to raise head slightly)."* For vision into the cockpit under the PNVG, the following negative comment was recorded: *"The right main channel was harder to get a good focus on when compared to the left main channel. It's a bit harder to scan the instruments with PNVG, but again it depends on the helmet/PNVG fit. The visor is useless."* The associated positive comment: *"Difficult to see under the PNVG when under G. Not a significant problem when straight and level."* No comments were recorded regarding clear visor compatibility.

COCKPIT/COCKPIT LIGHTING COMPATIBILITY: Cockpit clearance of the PNVG was rated during scanning behavior. In the operational position, clearance was rated better with PNVG than with F-4949 (mean rating = 3.81). In stowed position, clearance was similar that of the F-4949 (mean rating = 3.31). Cockpit display compatibility for PNVG was rated as similar to F-4949 (mean rating = 3.19). This was true also for HUD (mean rating = 3.17) and NVIS lighting (mean rating = 3.27) compatibility. PNVG was rated as more compatible with "Christmas tree" lighting (mean rating = 4.14) than the F-4949.

COCKPIT/COCKPIT LIGHTING COMPATIBILITY COMMENTS: Regarding cockpit scanning clearance in the operational position, only one applicable comment was recorded: *"No problems with bumping PNVGs against anything."* For the stowed position, the negative comment: *"In up position it is very close to hitting canopy if seat is near full up."* The positive comment: *"PNVG in the up position is not a problem during non-tactical flying. If you flew tactical with the PNVG up, you might hit the canopy."* For lighting compatibility, the following negative comment was recorded: *"The PNVGs are more sensitive, hence more taping/masking in the cockpit is required. Covering the mirrors and using the Glendale green plastic helped the light leakage problem."* The most positive comment for cockpit lighting compatibility: *"4012 is the best PNVG cockpit I've seen."* Only one comment was recorded for HUD lighting compatibility: *"Needed to be turned way up."*

IMAGE QUALITY: Overall PNVG image quality was rated slightly higher than F-4949 (mean rating = 3.47). Similar findings were recorded for a question addressing the ability to distinguish cultural (mean rating = 3.5) and terrain features (mean rating = 3.5). PNVG image brightness acceptability was rated higher than F-4949 (mean rating = 3.59). Image brightness consistency across the tubes was indicated during 69% of the sorties. The acceptability of image noise for PNVG was rated to be similar to F-4949 (mean rating = 3.44). Figure 5 shows the proportion of cases where various types of image effects were experienced.

IMAGE QUALITY COMMENTS: For overall PNVG image quality vs. F-4949 quality, the following negative comment was recorded: *"Worse than most 4949's I've flown with."* For the same topic, the following positive comment was recorded: *"Better in 3 channels, worse in 1 channel."* Only one comment was recorded related to the ability to distinguish cultural features via PNVG: *"Gross features easy to distinguish. Tough to see detail due to focus problems."* Regarding terrain features, the single comment was: *"Acceptable"*. A single comment associated with image brightness acceptability was: *"Not bright enough."* Comments related brightness consistency indicated the nature of the inconsistency: *"Right tube brighter."* Similarly, the comments related to the image effects were limited to a description of the effect.

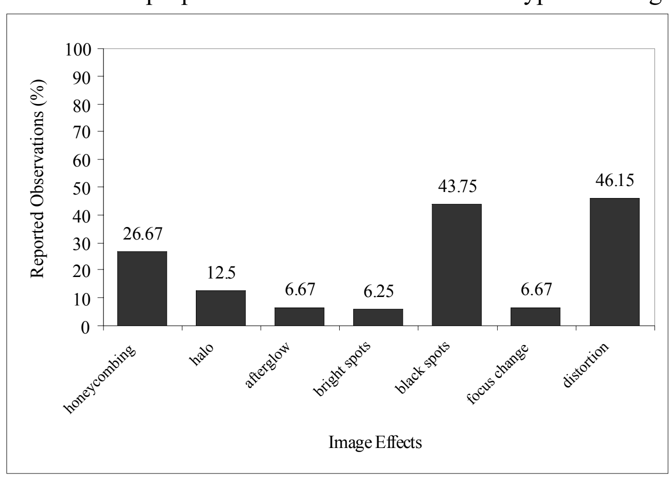


Figure 5. Proportion of image effects reported.

TACTICAL EMPLOYMENT: Pilots reported that 5.5 G's could be sustained comfortably while using the PNVG. The maximum reported G load across these test flights was 8.0. Pilots were asked if the PNVG ever inadvertently came down from the stowed position during the flight. This occurred during 2 of the 16 flights (12.5%). The pilots reported that overall, SA was enhanced by the use of PNVG compared to F-4949 (mean rating = 4.2). Figure 6 shows the pilots' mean ratings comparing PNVG and F-4949 across different tactical tasks. PNVG appears to have been most beneficial during threat detection, formation and tactics, offensive maneuvering, defensive maneuvering, and for survivability.

TACTICAL EMPLOYMENT COMMENTS: For the comparison of the PNVG to the F-4949 for an overall SA effect, the comments were very positive toward the PNVG FOV. The most negative comment was: *"[these low] ratings are due to a distorted picture."* On the positive side, the comments were consistent with: *"The PNVG/HMD was a huge leap in SA."* A similar pattern resulted throughout the tactical employment comments. See Table 3 for comments.

OVERALL COMPARISON: Pilots were asked to rate the suitability of the PNVG FOV compared to the F-4949 FOV. The results indicate that the pilots feel that the PNVG FOV is very effective (mean rating = 4.66). When asked to make an overall preference comparison of the PNVG vs. F-4949, 15 of the 16 responses indicate a preference for PNVG (93.33%).

OVERALL COMPARISON COMMENTS: For the question probing suitability of the PNVG compared to the F-4949, the following negative comment was recorded: *"4949 better for detail. PNVGs better overall performance due to increased FOV."* The positive comment: *"PNVG good for low altitude with the better peripheral view, especially near rugged terrain."* For overall preference, only one negative comment was recorded: *"[Not] able to wear glasses, [not] able to stow and pull g's if required. However, if these can be fixed, PNVGs would be my choice."* Two comments capture the preference for the PNVG: *"Better SA, less disorientation. [Liked] panoramic view, comfort, mission effectiveness, SA."* The following comments sections are in response to questions regarding the best features and biggest drawbacks of the PNVG.

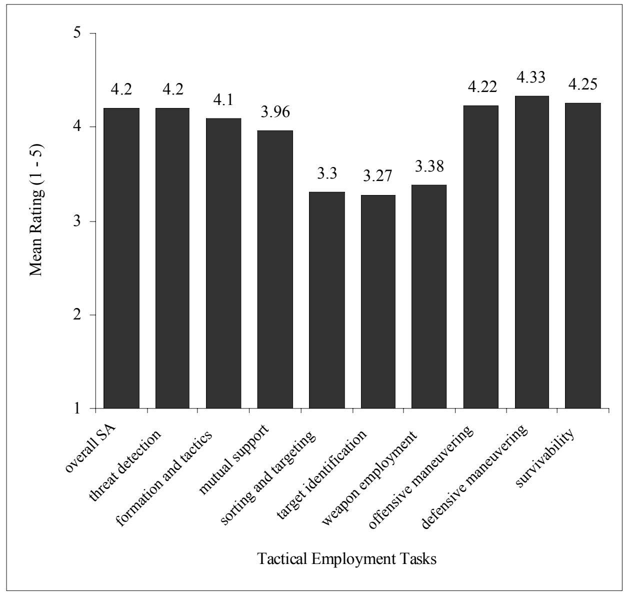


Figure 6. Mean rating scores across tactical tasks

Tactical task	Most negative comment	Most positive comment
Threat detection	*"Much better than 4949. Would be great with better focus."*	*"Superior in every way."*
Formation and tactics	*"Easier to fly close to line abreast but still not able to fly day tactical."*	*"Panoramic makes formation flying much easier from either the flight lead or wingman position."*
Mutual support	*"Same as formation and tactics."*	*"Much better than F-4949."*
Sorting and targeting	No comments.	No comments.
Target identification	*"Needs better focus."*	*"Much better."*
Weapon Employment	No comments.	No comments.
Offensive maneuvering	*"Not required to point my head directly at the high LOS bandit. No fear of losing him."*	*"Much easier to maneuver aggressively."*
Defensive maneuvering	*"Easier to notch and maintain SA on the horizon."*	*"Additional FOV very helpful in high aspect or defensive situation—used the outer channels a lot during maneuvering."*
Survivability	No comments.	No comments.

Table 3. Tactical employment comments.

BEST FEATURES OF THE PNVG: "I did not experience any eye strain or headaches." "A must have." "A-10's need these!" "Closer to face, better FOV rather obvious!" "Outer channels were focused much better (20/25)." "Had better SA awareness of my surroundings." "Easier to fly at lower altitudes." "Could spend more time scanning for bandits and watching where my flight path is." "Less forward CG when looking through."

BIGGEST DRAWBACKS OF THE PNVG: *"Lack of adjustability." "The battery change out is unsat." "I lost a battery down inside the helmet cover when trying to change out!" "In order to see the HMD display, I had to have the right channels way over to the left (toward the center of my face)." "This caused me to lose the outer part of the right outer channel." "Need to adjust focus rings." "They are too hard to work with gloves on." "Need more play in the areas that we normally focus (infinity)." "The "bridge" that holds the goggle is worn and breaks loose at 6 g's or greater." "Requires me to reach up and snap it back into place." "More difficult to see inside the cockpit, especially under g's." "Very difficult to set up the*

radar while in turn." "Not as crisp." "Flimsy trapeze, tilt sags under G." "Adjustments not user friendly." "Had to lower seat 2 inches to get proper eye height relative to HUD." "Delicate innards exposed when removed from helmet for stowing."

CONCLUSION

The PNVG feedback has been very positive and indicates that a 100 degree FOV significantly improves pilot performance across different operational tasks compared to the 40 degree F-4949. Tactics that had previously been used with F-4949 are not necessarily applicable anymore. The PNVG significant increase in intensified FOV affords daytime-like tactics at night. This pilot feedback is not complete. Additional flights on F-15s as well as other aircraft will be used for further evaluation. Suggested areas for PNVG improvements will be addressed in an upcoming follow-on advanced technology demonstration program.

ACKNOWLEDGMENTS

This paper would not have been possible without the excellent support and feedback from the 422nd Test and Evaluation Squadron at Nellis AFB, Nevada and the outstanding management from the Helmet-Mounted Sensory Technologies Program Office at Wright-Patterson AFB, Ohio.

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BIOGRAPHIES

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